PANYNJ Airfield Fatigue Cracking Study

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Center for Advanced Infrastructure and Transportation (CAIT)

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Acknowledgements

- Rutgers Staff
  - Chris Ericson, M.S.
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  - Casimir Bognacki, Chief of Materials Bureau
  - John Tetar, Asphalt Laboratory Manager
Objective of Study

- Evaluate different runway P401 mixtures for their respective fatigue cracking performance
  - 5 different mixes
  - Different asphalt binders
  - Different field performance
    - 15 years – performing well
    - 6 years – performing poorly
- “Fatigue” asphalt binder testing
- Mixture fatigue cracking tests
- Ultimately – can we find a binder parameter for purchase specification and mixture specification for Quality Control to promote durable asphalt mixtures
Field Observations

- Longitudinal and transverse cracking observed
- Cracking top-down
  - Stops approximately 0.5 to 0.75 inches below surface
# Newark & JFK Runway Fatigue Cracking

<table>
<thead>
<tr>
<th>Runway</th>
<th>Core Location</th>
<th>Core Thickness</th>
<th>Mix Type</th>
<th>Binder Type</th>
<th>Supplier</th>
<th>Visual Observations</th>
<th>Aggregate Type</th>
<th>Date Placed (Age)</th>
<th># of Cores</th>
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<tbody>
<tr>
<td>EWR 11-29</td>
<td>Station 38+84, Offset 16 ft, Right of Centerline</td>
<td>2 inches</td>
<td>FAA #3</td>
<td>PG64-22 + 7% Vestoplast</td>
<td>Mt. Hope, Tilcon B Plant</td>
<td>Not performing well; Excessive cracking</td>
<td>Gneiss</td>
<td>9/20/2008 (6 Yrs, 9 Months)</td>
<td>11 (1 cracked)</td>
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<tr>
<td>(Core Set 1)</td>
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<td>8/9/2008 (6 Yrs, 10 Months)</td>
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<td>3 inches</td>
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<td>PG76-22</td>
<td>Willets Pt Asphalt, flushing, NY</td>
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<td>Trap Rock (from Tilcon, Haverstraw)</td>
<td>9/5/2002 (12 Yrs, 9 Months)</td>
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<td>PG76-28</td>
<td>Willets Pt Asphalt, flushing, NY</td>
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<td>Trap Rock (from Tilcon, Haverstraw)</td>
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<td>Gneiss</td>
<td>6/4/2000 (15 Yrs)</td>
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<td>(Core Set 5)</td>
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<tr>
<th>Runway</th>
<th>Binder Type</th>
<th>Asphalt Content</th>
<th>QC Air Voids</th>
<th>QC VMA</th>
<th>QC VFA</th>
<th>Eff AC by Vol (%)</th>
<th>Flow</th>
<th>#200</th>
<th>#200/Eff AC by Vol</th>
<th>Visual Observations</th>
<th>Date Placed (Age)</th>
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<td>12.4</td>
<td>11.8</td>
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</table>
Asphalt binder testing conducted every 0.5” to evaluate change in binder properties due to aging.

Asphalt mixture testing conducted at bottom of core to provide “initial” mixture performance.
Asphalt Binder Testing & Results
- Master Stiffness ($G^*$) curves generated using frequency sweep in the DSR
- Shape of master curve related to overall stiffness of the asphalt binder
- As binders age, increase in stiffening
PG64-22 & PG76-22 in $\omega_o$ & R-value Space

![Graph showing crossover frequency and R-value for PG64-22 and PG76-22 asphalt binders under different aging conditions.](image-url)
Cross-over Frequency ($\omega_o$) – R-value Space

- Newark, Set #1
- Newark, Set #2
- JFK, Set #3
- JFK, Set #4
- JFK, Set #5
ΔT_c from BBR Testing

- Ductility has always been correlated to fatigue performance of asphalt mixtures and clearly decreases with aging.
- As asphalt binders age, the relaxation properties (m-value) are negatively affected at greater rate than the stiffness (S).
- The difference between the low temperature cracking grade of m-value and S is defined as the ΔT_c

\[ ΔT_c = T_{c, S} - T_{c, m-value} \]

- AAPT (Anderson et al., 2011) showed that the ΔT_c correlated to non-load associated cracking on airfields (i.e. – cracking mainly due to aging), as well as ductility.
Change in Low Temperature Critical Cracking ($\Delta T_c$)

\[ T_c = T_c, s - T_c, m-value \]

![Graph showing change in low temperature critical cracking with depth from surface and temperature difference ($T_c$).](image)

- Newark, Set #1
- Newark, Set #2
- JFK, Set #3
- JFK, Set #4
- JFK, Set #5
- Crack Warning
- Crack Limit
Double Edge Notched Tension (DENT) Test – AASHTO TP113

- Test evaluates the energy required for fracturing ductile materials
  - Test measures the Work of Fracture and Critical Opening Displacement (CTOD)
  - CTOD represents ultimate elongation, or strain tolerance, in the vicinity of a crack (i.e. – notch)
  - As CTOD increases, more resistant to fracturing
- Test has been found to correlate well to field cracking performance at FHWA ALF, as well as laboratory studies at Rutgers U. and TTI
Double Edge Notched Tension (DENT) Test – AASHTO TP113 (20°C)
Glover-Rowe Parameter (G-R)

- Due to equipment and material size restraints, Ductility testing may not be available.
- Rowe (AAPT, 2011) proposed the DSR master curve analysis to calculate the “Glover-Rowe” parameter:
  - As G-R parameter increases, the binder is more prone to fatigue cracking.
  - Correlates to both ductility and BBR ΔTc.
- Laboratory testing at Rutgers U. has shown the parameter correlates to lab fatigue performance.
Glover-Rowe Parameter (G-R)

![Graph showing the Glover-Rowe Parameter (G-R) values for different sets.

- Newark, Set #1
- Newark, Set #2
- JFK, Set #3
- JFK, Set #4
- JFK, Set #5
- Crack Onset

The graph illustrates the relationship between depth from surface (inches) and Glover-Rowe Parameter (kPa). Each set is represented by different colors and markers.

Legend:
- Newark, Set #1: Blue circles
- Newark, Set #2: Orange circles
- JFK, Set #3: Gray circles
- JFK, Set #4: Yellow circles
- JFK, Set #5: Blue squares
- Crack Onset: Red dashed line

Depth from Surface (inches):
- 0.0
- 0.25
- 0.50
- 0.75
- 1.00
- 1.25
- 1.50
- 1.75
- 2.00
- 2.25
- 2.50

Glover-Rowe Parameter (kPa):
- 0.1
- 1.0
- 10.0
- 100.0
- 1000.0

The graph shows the trend of the Glover-Rowe Parameter with increasing depth from the surface for different sets.
Linear Amplitude Sweep (LAS) – AASHTO TP101

- Utilizes cyclic testing in the DSR to evaluate the undamaged and damaged condition of asphalt binders under increased accelerated damage.
- Analysis allows for the determination of asphalt binder fatigue life (cycles) at different shear strain levels.
- Comparison to FHWA-ALF and LTPP sections show relatively well correlations.
Linear Amplitude Sweep @ 2.5% Shear Strain

LAS Fatigue Life Cycles @ 2.5% Shear Strain (cycles)
# Binder “Fatigue” Test - Ranking of Core Sets

<table>
<thead>
<tr>
<th>Depth</th>
<th>Runway</th>
<th>Binder Type</th>
<th>Visual Observations</th>
<th>Date Placed (Age)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25&quot;</td>
<td>EWR 11-29 (Core Set 1)</td>
<td>PG64-22 + 7% Vestoplast</td>
<td>Not performing well; Excessive cracking</td>
<td>9/20/2008 (6 Yrs, 9 Months)</td>
</tr>
<tr>
<td></td>
<td>EWR 11-29 (Core Set 2)</td>
<td>PG64-22 + 7% Vestoplast</td>
<td>Not performing well; Excessive cracking</td>
<td>8/9/2008 (6 Yrs, 10 Months)</td>
</tr>
<tr>
<td></td>
<td>JFK 4R-22L (Core Set 3)</td>
<td>PG76-22</td>
<td>Performing well; No cracking</td>
<td>9/5/2002 (12 Yrs, 9 Months)</td>
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<tr>
<td></td>
<td>JFK 4L-22R (Core Set 4)</td>
<td>PG76-28</td>
<td>Performing well; Very few cracks</td>
<td>6/4/2000 (15 Yrs)</td>
</tr>
<tr>
<td></td>
<td>JFK 4L-22R (Core Set 5)</td>
<td>PG76-28</td>
<td>Performing well; some cracking</td>
<td>6/4/2000 (15 Yrs)</td>
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<table>
<thead>
<tr>
<th>Depth</th>
<th>Tcr</th>
<th>CTOD (mm)</th>
<th>Glover-Rowe</th>
<th>Average</th>
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<td>0.25&quot;</td>
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<td>JFK, Set #5</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2.0</td>
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</table>
Both the BBR $\Delta T_c$ and DENT CTOD properties correlated to field observations

- Glover-Rowe provided reasonable comparisons
- Intermediate PG grade & LAS conflicted to field observations

“Fatigue” properties of recovered asphalt binder improved with depth

- At depths > 0.75 inches, appears to be little aging
  - Would change based on in-situ air voids – these mixtures all placed at air voids < 6.5%

Could bottom portion of 1.5 to 2 inch core be used to develop laboratory to field binder and mixture aging protocols?
Asphalt Mixture Testing & Results
Asphalt Mixture Testing

- Two fatigue tests conducted on recovered cores
  - Semi-circular Bend (SCB) Test (AASHTO TP105)
  - Overlay Tester (NJDOT B-10; TxDOT TEX-248F)
- Tests chosen based on personal experience and performance correlations in the literature
- Tests also allow thin specimens to be used, which is ideal for either laboratory compacted specimens or field cores
- Test specimens taken away from surface (> 0.75 inches from surface) to obtain asphalt materials that represented close to “original” placement
  - Can the mixture tests predict the resultant field performance?
Semi-circular Bend (SCB) Test

- Uses 3-point bending on a semi-circular asphalt sample
- Can use same equipment at AASHTO T283 (50 mm/min)
- Notch cut to initiate cracking
- Test evaluates the energy required to fracture the specimen and propagate a crack at the notch
  - Work of Fracture
- Additional analysis was used to calculate the Flexibility Index (FI)

![Flexibility Index](image)
Semi-circular Bend (SCB) Flexibility Index (FI)

- Flexibility Index (FI) shows that Newark Sets #1 and #2 have the worst fatigue resistance.
- JFK Set #3 should have best fatigue performance, followed by Set #5 and Set #4.
**Overlay Tester**

- **Sample size**: 6” long by 3” wide by 1.5” high
- **Loading**: Continuously triangular displacement 5 sec loading and 5 sec unloading
- **Definition of failure**
  - Discontinuity in Load vs Displacement curve
Overlay Tester

- Overlay Tester results indicate that Newark Core Set #1 and #2 should perform the worst.
- JFK Set #5 should have the best fatigue performance, followed by JFK Set #4 and Set #3.
# Mixture Ranking of Core Sets

<table>
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<tr>
<th>Core Set</th>
<th>SCB Flexibility Index</th>
<th>Overlay Tester</th>
<th>Average</th>
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<td>1.5</td>
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<tr>
<th>Runway</th>
<th>Binder Type</th>
<th>Visual Observations</th>
<th>Date Placed (Age)</th>
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<tbody>
<tr>
<td>EWR 11-29 (Core Set 1)</td>
<td>PG64-22 + 7% Vestoplast</td>
<td>Not performing well; Excessive cracking</td>
<td>9/20/2008 (6 Yrs, 9 Months)</td>
</tr>
<tr>
<td>EWR 11-29 (Core Set 2)</td>
<td>PG64-22 + 7% Vestoplast</td>
<td>Not performing well; Excessive cracking</td>
<td>8/9/2008 (6 Yrs, 10 Months)</td>
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<tr>
<td>JFK 4R-22L (Core Set 3)</td>
<td>PG76-22</td>
<td>Performing well; No cracking</td>
<td>9/5/2002 (12 Yrs, 9 Months)</td>
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<tr>
<td>JFK 4L-22R (Core Set 4)</td>
<td>PG76-28</td>
<td>Performing well; Very few cracks</td>
<td>6/4/2000 (15 Yrs)</td>
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<tr>
<td>JFK 4L-22R (Core Set 5)</td>
<td>PG76-28</td>
<td>Performing well; some cracking</td>
<td>6/4/2000 (15 Yrs)</td>
</tr>
</tbody>
</table>
Conclusions

- **Asphalt Binder**
  - The $\Delta T_c$ from the BBR and the DENT CTOD tests appeared to correlate the best to field observations of cracking. Glover-Rowe also showed promise.
  - Results from 0.75” depth and deeper resulted in better correlation to field performance
    - De-icing materials, fuel/oil contamination, residual rubber from tires, etc.

- **Asphalt Mixture**
  - Both the SCB and the Overlay Tester fatigue cracking performance matched the field performance
Conclusions - continued

- Potential Implementation
  - $\Delta T_c$ from the BBR and the DENT CTOD tests can be used as a PG+ specification (specification in addition to current specs) to help insure durability in asphalt binder
    - Need to determine at what aging condition for binder - RECOMMENDED
      - 20 Hr PAV may not be enough
      - 40 Hr PAV proposed by some
  - Mixture testing (SCB or Overlay Tester) can be used post-production to ensure the mixture is properly being produced
    - SCB can be run on current asphalt plant equipment using Marshall Compression machine and modified loading head
Potential SCB Plant Implementation – Sample Trimming
Potential SCB Plant Implementation – Cutting Notch

(1)

(2)

(3)
Potential SCB Implementation – Marshall Press
Potential SCB Implementation – Rutgers MTS
Comparison of Rutgers MTS & Marshall Press

![Bar graph showing flexibility index (FI) for Rutgers MTS, Rutgers Marshall Equipment Type/Analysis, Rutgers MTS (ILL), and Rutgers Marshall (ILL).]

- Rutgers MTS: 8.3
- Rutgers Marshall Equipment Type/Analysis: 6.52
- Rutgers MTS (ILL): 7.6
- Rutgers Marshall (ILL): 5.6
Potential SCB Implementation - Needs

- Wet saw for preparing samples
- 3 point loading fixture
- Rounded loading head for line load (modified Lottman too wide)
- Conditioning test specimens – tests conducted at 25°C and used environmental chamber
  - QC lab could use a water bath and place specimen in sealed, plastic bag
- Questions to be answered:
  - Criteria – what is pass/fail?
    - Study’s field cores would indicate Flexibility Index > 20 ~ 25
  - What type of test specimen? QC sample? Compacted to target air voids?
  - Should test specimens be long-term aged?
Thank you for your time!

Questions?

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